Reference Manual
for
SIM Common-View Time and Frequency
Measurement System

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TABLE OF CONTENTS

Calibration results follow page 15. The calibration was performed done by making a common-clock comparison to the master NIST system for a period of 10 days (240 hours). The CENAMEP system was calibrated using an Rx delay of 100 ns. Based on a average relative delay difference of 48.69 ns over a 10-day interval when compared to the calibrated NIST system, the Rx delay was changed to 51 ns. The resolution of the Rx delay value is 1 ns.

CENAMEP System Information

SIM ID: **9**

Result of Rx delay calibration: 51 nanoseconds, using supplied antenna/cable

Web Link: **http://gpsmonitor.timefreq.bldrdoc.gov/control/simnet.htm**

Web User Name: cvgps001

Web Password: SIM001

I.   Introduction

The SIM common-view time and frequency measurement system is designed to continually measure a laboratory's primary time and frequency standard with respect to the national standards of all other participating SIM laboratories. All comparisons are made using the multi-channel common-view GPS measurement technique.   Each participating laboratory is required to connect a stable 5 or 10 MHz signal to the system to serve as a time base, and to provide a 1 Hz signal from their primary standard or UTC time scale. The 1 Hz signal should preferably be on-time, since the system can display the absolute time offset between laboratories with an uncertainty of less than 50 ns.

The system does not analyze or graph the data; it simply collects and stores it. The collected data is sent to a Web server located at NIST using the Internet file transfer protocol (FTP).   The client can view the raw data and time difference graphs using a standard web browser.

The following instructions explain how to use the system. The instructions are divided into three sections: installation, operation, and viewing data on the Web.

Keep in mind that this system should perform as described here, but if not, please report all problems to NIST so that updates to the software and/or documentation can be made if necessary.

II.   Installation

The system requires four input connections:

- **GPS Antenna (TNC cable)**

Mount the supplied GPS antenna on a rooftop location with an unobstructed view of the sky on all sides. Use the supplied pole and mounting hardware to mount the antenna. Run the supplied antenna cable down to the lab where the measurement system is located.

Connect the GPS antenna cable to the TNC connector on the rear panel of the system that is labeled "ANTENNA".

- **Reference signal (1 Hz)**

Connect a 1 Hz signal from your laboratory's primary time and frequency standard to the BNC connector on the rear panel labeled "REFERENCE (UTC)".

- **External Time Base (BNC, must be 5 or 10 MHz)**

Connect a 5 or 10 MHz signal from a stable frequency standard to the BNC connector labeled "TIMEBASE" on the rear panel. The signal level should be between 200 mV and 3.5 V peak-to-peak, or 70 mV to 1.25 V (rms) with 50 Ω termination. This signal can originate from the same standard as the 1 Hz signal.

- **Network Connection**

The system contains an Ethernet card for connection to the Internet. It must be connected to the Internet using a dedicated IP address. If you know this IP address in advance, NIST can configure the system for you. Otherwise, perform the following steps:

- ➢ Click on the START button in Windows, then click Settings, then Network and Dial-up Connection

- ➢ Doubleclick on Local Area Connection, then click on Properties

- ➢ Doubleclick on Internet Protocol (TCP/IP)

- ➢ Enter the IP address, Subnet mask, Default gateway and DNS servers

III.   Configuring the System

After the computer is turned on and Windows 2000 has completed loading, the software should run automatically. You will then see a display similar to Figure Figure II.1 below:

Figure II.1. Initial Screen Display

Some of the fields near the bottom left corner of the SIM window might already contain information, but this information will need to be verified and changed if necessary before making measurements. To make changes, point to and click on the field that you want to edit. The fields are described below:

TIC Time Base	This field allows you to select the frequency of your time base oscillator (either 5 MHz or 10 MHz). The system requires a stable external time base oscillator in order to work properly.
SIM ID	This is the unique number that identifies your laboratory. It cannot be changed without editing a system file, and **should not be changed.**

Contact	The name of a contact, or the name of the group or division within the laboratory or organization.
Laboratory	The name of the laboratory or organization.
Reference	The manufacturer and model number of the primary standard, for example, "Hewlett-Packard 5071 Cesium", or the name of the laboratory's primary time scale, for example, "UTC(NIST)".
Ref Delay	This number should be entered in units of nanoseconds. It is the estimated delay in the cable that connects the laboratory's primary standard (1 Hz signal) to the measurement system. If a distribution amplifier is used, it must include the delay in the distribution system. Cable delays can usually be measured with an uncertainty of about 1 nanosecond using a time interval counter.
Rx Delay	This number should be entered in units of nanoseconds. It represents the combined delay of the GPS receiver, antenna, and antenna cable. Since it is common for the GPS receiver to actually advance the timing pulse (in some cases by tens of nanoseconds), the receiver itself usually has a "negative" delay. Therefore, this number might be considerably smaller than the actual antenna cable delay. NIST normally supplies the Rx delay number, since it usually calibrates all units prior to shipment, and ships the measurement system with the same antenna and cable used during the calibration.
Mask Angle	The mask angle determines the elevation angle above the horizon where satellites will be tracked. It can be set from 0 to 25° in 5° increments. Raising the mask angle reduces the number of visible satellites, and for most receiving locations, a mask angle of 5 or 10° is recommended.
FTP	This is normally set to Y, so that the collected data can be uploaded to an external web server every 10 minutes. In order for the file transfers to work, the system must be connected to an always-on Internet connection, and it must have a dedicated IP address that has been sent to NIST for authentication purposes.

IV.   Antenna Position

After the configuration information has been entered, the next step is to establish the GPS antenna coordinates. This can be done either by entering the coordinates if they are previously known, or by allowing the system to survey its own antenna position. Once the antenna position is known it is saved by the system and used for all further measurements, so this process does not need to be repeated unless the antenna is moved. The uncertainty of the antenna position directly contributes to the uncertainty of the time and frequency measurements recorded by the system, so it is important to use the best antenna coordinates that you have available. Note that if the system surveys its own position, the latitude and longitude values are often very accurate (within a few meters or less), but the altitude estimate can remain in error by as much as 20 meters, so an independent survey is often necessary for best results.

To manually enter the antenna position:

- Click the *Coordinates* button. A window appears as shown in Figure III.1.
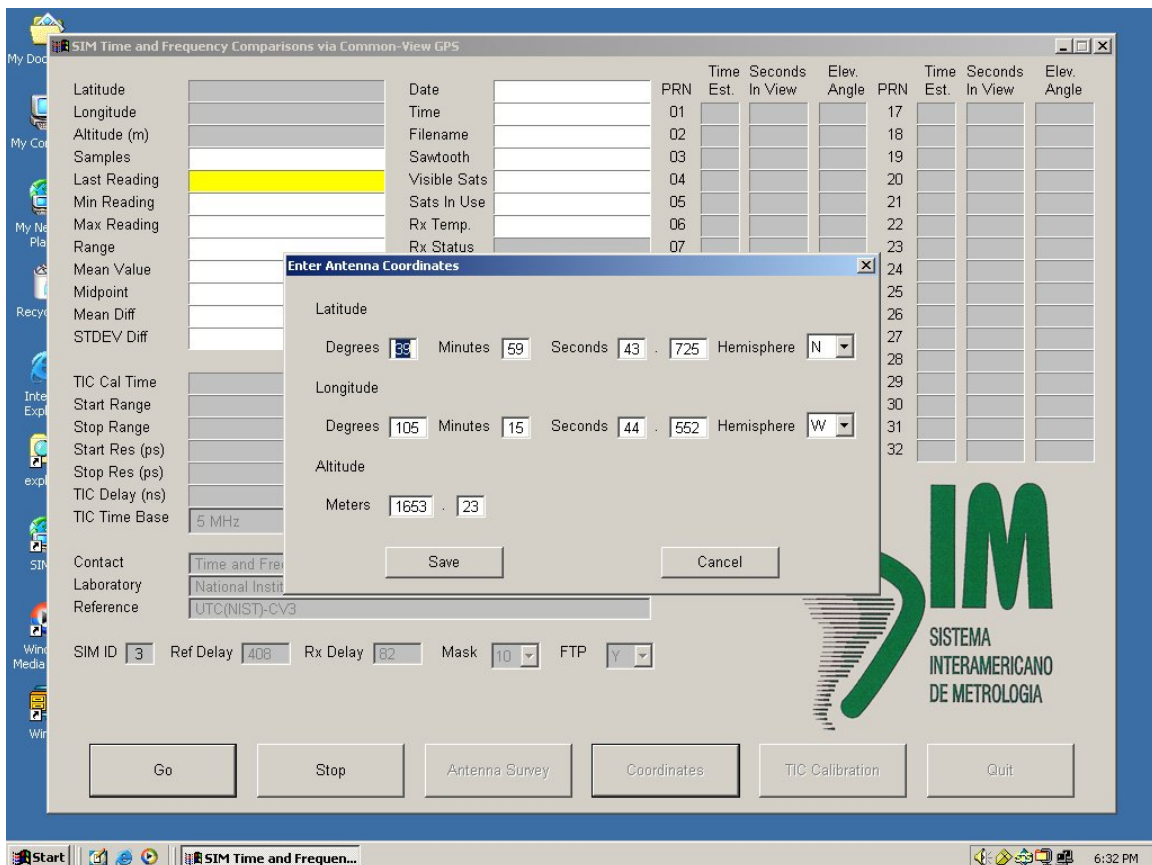

Figure III.1. The Enter Coordinates Window

- Enter the antenna coordinates. The allowable resolution is 1 milliarcsecond for latitude and longitude, and 1 centimeter for altitude.

- When finished, click the *Save* button.

To have the system survey its antenna position:

- Click the *Antenna Survey* button.

- The receiver will be reset and begin to look for satellites. It might take up to 20 minutes before it produces its first position fix. Once the first position fix is obtained, coordinates are averaged for 24 hours (86,400 seconds), so the entire antenna survey takes slightly more than 24 hours to complete.

- During the antenna survey, the latitude, longitude, and altitude fields will updated, and the samples field will show the number of position fixes that have been averaged so far.

- After 86,400 valid position fixes have been obtained, the average antenna position is saved and the system is ready to begin measurements.

V.   Making Measurements

After the antenna position data is available, click the *Go* button to start the measurements. At this point, the system will calibrate the time interval counter, check the status of the GPS receiver, and then begin to collect and store measurements. When the measurements have begun, the screen display will look similar to Figure V.1. Leave the system running in this mode with the measurement screen displayed at all times. If it is ever necessary to stop the measurements, click the *Stop* button.
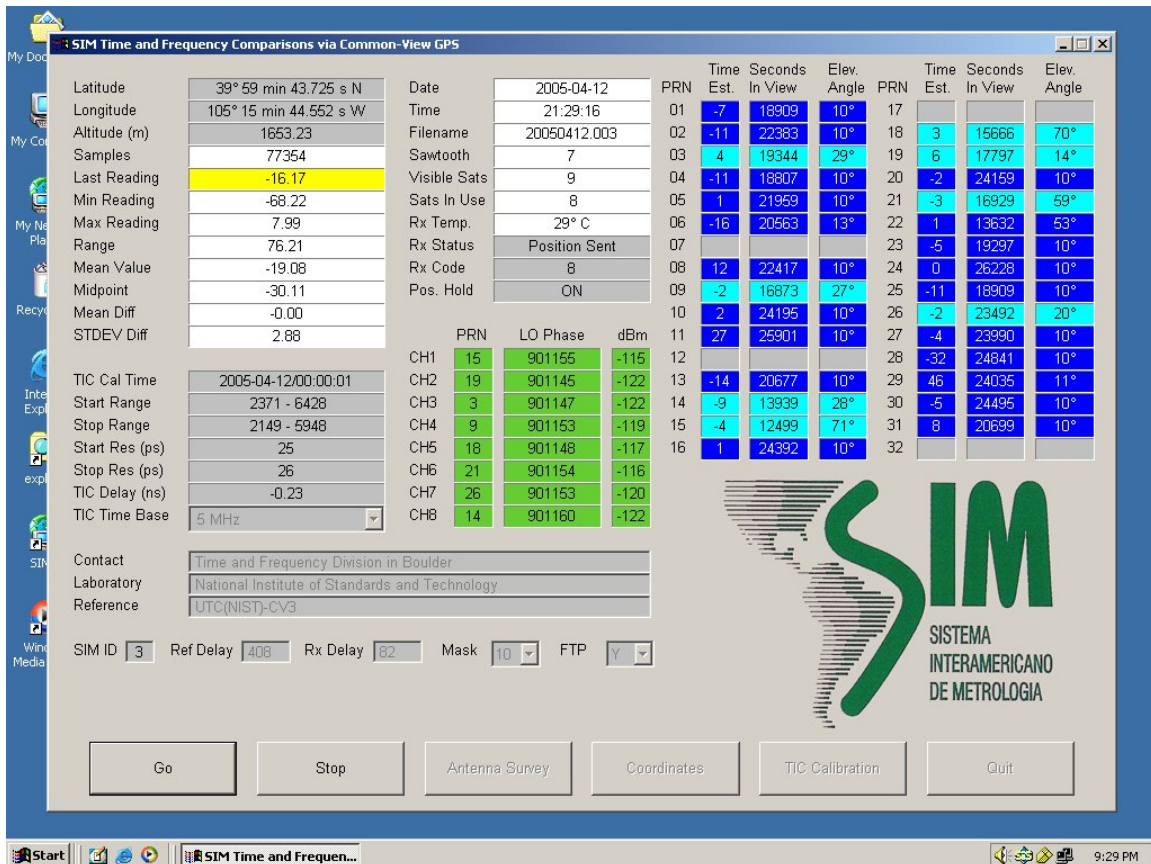

Figure V.1. The Measurement Screen

The measurement screen is divided into three areas (left, middle, and right). The following tables describe what the numbers in each area mean.

Table V.1. Left Area of Measurement Screen

Table Heading	Description of Item
Latitude	The latitude of the GPS antenna, as determined by the antenna survey or as entered by the user. The available resolution is 1 milliarcsecond.
Longitude	The longitude of the GPS antenna, as determined by the antenna survey or as entered by the user. The available resolution is 1 milliarcsecond.
Altitude	The altitude of the GPS antenna, as determined by the antenna survey or as entered by the user. The available resolution is 1 centimeter.
Samples	The number of data samples recorded so far during the current day. One sample is recorded every second, so 86400 samples are recorded per day.
Last Reading	The most recent reading from the time interval counter (displayed on a yellow background). The unit is nanoseconds. If the timing pulse from the GPS receiver is early with respect to the local standard, a negative number will be displayed. This is normal.
Min Reading	The smallest reading recorded from the time interval counter during the current day. The unit is nanoseconds.
Max Reading	The largest reading recording from the time interval counter during the current day. The unit is nanoseconds.
Range	The maximum reading minus the minimum reading, in nanoseconds. This gives an indication of the worst case timing uncertainty of the system during the current day.
Mean Value	The total of all readings divided by the number of samples, in nanoseconds.
Midpoint	The midpoint of all readings, in nanoseconds.
Mean Diff	The average difference between two successive readings, given in nanoseconds. This number will often be close to zero.
STDEV Diff	The standard deviation of the difference between two successive readings, given in nanoseconds. This number provides a rough estimate of the timing stability of the system at an averaging time of 1 second.

TIC Cal Time	The date and time when the time interval counter (TIC) was last calibrated. The TIC is calibrated immediately prior to a measurement run and at the beginning of each UTC day. During the calibration, this field will display the messages "IN PROGRESS" and "TRANSITION". If the calibration fails, that will also be indicated in this field as "CALIBRATION FAILED".
Start Range	The counting range (min to max) of the TIC's start interpolator during a 100 nanosecond interval, displayed only for diagnostic purposes.
Stop Range	The counting range (min to max) of the TIC's stop interpolator during a 100 nanosecond interval, displayed only for diagnostic purposes.
Start Res (ps)	The resolution of the start input on the time interval counter, given in picoseconds. It is equal to the start range (max – min) divided by 100 nanoseconds. The resolution should be 30 picoseconds or less, and should be nearly equivalent to "Stop Res".
Stop Res (ps)	The resolution of the stop input on the time interval counter, given in picoseconds. It is equal to the start range (max – min) divided by 100 nanoseconds. The resolution should be 30 picoseconds or less, and should be nearly equivalent to "Start Res".
TIC Delay (ns)	The time offset due to delays in the time interval counter, given in nanoseconds. This number is used as a correction value that is applied to each reading. It is usually less than 0.5 ns.

Table V.2. Middle Area of Measurement Screen

Table Heading	Description of Item
Date	The current date read from the GPS receiver.
Time	The current time read from the GPS receiver. Due to the screen updating procedure, the displayed time has an uncertainty of ± 1 second.
Filename	The filename currently being created by the system. The format for the name is YYYYMMDD. The file extension is the SIM ID. One file is created per day.
Sawtooth	The timing pulse produced by the receiver is ambiguous to local oscillator clock cycles, due to the nature of the receiver hardware. However, the receiver firmware keeps track of the offset of the next timing pulse, and that number is displayed here and applied by the system as a "sawtooth" correction. The correction ranges from -52 to $+52$ ns.
Visible Sats	The number of satellites currently visible to the GPS receiver. This number can be as high as 12, but the receiver is only capable of tracking 8 satellites at one time.
Sats in Use	The number of satellites currently being tracked. The maximum number is 8.
Rx Temp.	The temperature obtained from a sensor on the CPU board inside the computer case, near the GPS receiver. This sensor is read every second, but the resolution is 1° C, so the readings generally do not change rapidly. The temperature tends to be a few degrees higher than the laboratory temperature, and to fluctuate as the laboratory temperature fluctuates. For best results, it is important to not let the temperature change rapidly by keeping the receiver in a room where the temperature fluctuations do not exceed $\pm 3°$ C.
Rx Status	This field contains a text message that normally only changes during signal acquisition or an antenna survey. When the system is taking readings, the displayed message will read "Position Sent".
Rx Code	This field contains a number ranging from 1 to 255 that indicates the receiver status. If the receiver is operating

	properly, the number should always be an 8 or a 32. Other numbers will appear during the acquisition or antenna survey process and can be ignored.
Pos. Hold	ON means that the system is using a fixed antenna position, and is not trying to calculate further position fixes. OFF will only appear during signal acquisition or an antenna survey.
Box with green background	The "green" box contains information about each of the 8 channels on the GPS receiver. If one the channels is not being used, the information is printed on a light red background. The "PRN" column contains the psuedo random noise code (PRN) for each satellite being tracked. PRN codes have possible values ranging from 1 to 32. The "LO Phase" column shows the current phase (in nanoseconds) of the GPS receiver's local oscillator (LO) with respect to the received GPS signal. These numbers change rapidly, by more than 10 microseconds per second, because the LO has an intentionally introduced frequency offset that exceeds 1×10^{-5}. This offset is removed when the timing solution is produced. The numbers are displayed only for diagnostic purposes and to show that the receiver is tracking satellites. The "dBm" column shows the signal strength of each satellite being tracked. These numbers should normally be in the -115 to -135 dBm range and are generally accurate to about ±2 dB. The smallest number that can be displayed here is -163 dBm, which will often be seen when no satellite is available. Numbers smaller than -135 dBm on all channels could indicate that the antenna cable is too long or that local signal conditions are poor.

The right area of the screen provides data collected from all GPS satellites in view. The data is organized in row numbers labeled with the PRN numbers from the satellites. The 32 rows represent all possible slots in the GPS constellation, and it is not likely that all possible slots will contain satellites.

Table V.3. Right Area of Measurement Screen

Table Heading	Description of Item
Time Est.	The time difference (in nanoseconds) between the last reading recorded from the specified satellite and the average value of all satellites in view. If the background on this field is light blue, it means that the satellite is currently part of the timing solution, and this field is updating every second. If the background of this field is dark blue, it is not currently updating, and it contains the last recorded time estimate from the satellite. In some cases, the last recorded time estimate might be a fairly large number, which is why the satellite was dropped from the timing solution.
Seconds in View	The number of samples collected from the specified PRN during the current UTC day. The GPS satellites have an orbital period of approximately 12 hours, and therefore pass over a given location on earth twice each day. The receive tracks each satellite down to the selected mask angle. With a 10° mask angle it is not uncommon to collect more than 400 minutes (24000 seconds) of data from a satellite each day. Since the receiver has an 8-channel capacity and more than 8 satellites are sometimes in view, not all satellites will be tracked on both of their passes. If the background on this field is light blue, it means that the satellite is currently part of the timing solution, and this field is updating every second. If the background of this field is dark blue, it is not currently updating, but this indicates the satellite was being tracked earlier in the UTC day.
Elev. Angle	If the background of this field is light blue, it shows the current elevation angle of the satellite being tracked. If the background of the field is dark blue, it shows the elevation angle of the satellite at the moment when it was dropped from the timing solution. Normally, the values shown on a dark blue background will be equivalent to the mask angle, since satellites are dropped from the timing solution when their elevation angle is lower than the mask angle. However, in cases where more than 8 visible satellites are available for selection, or when a specific satellite is producing bad data, the receiver might drop a satellite from the

solution when it is still well above the mask angle. Therefore, you will sometimes see elevation angles high than the mask angle printed on a dark blue background.

NOTE: Once the system is operational, it will continue to take measurements unless there is a power outage, or if it is stopped by the operator. The measurement screen will reset at the end of each UTC day, erasing the old information and beginning the collection of new information. If the system is stopped for any reason, you can restart it by clicking on the SIM GPS Common-View icon, and then clicking the *Go* button.

VI.   Viewing the Data on the Web

When the system is running properly, it will send data every 10 minutes to a web server located at NIST. This data can then be viewed using any web browser with new data made available every 10 minutes. The web software allows up to 200 days of data to be displayed at one time.

To view the data collected at all participating SIM laboratories, visit this link:

http://gpsmonitor.timefreq.bldrdoc.gov/control/simnet.htm

To access the page, use the following information:

User name: cvgps001
Password: SIM001

The page allows you to view common-view GPS comparisons between any two participating SIM laboratories, or one-way GPS data recorded at any participating SIM laboratory.

UTC(NIST) versus UTC(NIST) via Common-View GPS

Laboratory 1	National Institute of Standards and Technology	ID Number	009	End Date	2005-09-04
Latitude	39° 59 min 44.308 s N	Counter Delay	-0.10 ns	Reference Source	UTC(NIST)
Longitude	105° 15 min 43.344 s W	REF Delay	772 ns	Mask Angle	10°
Altitude	1645.52 m	Receiver Delay	100 ns	Receiver Temp.	25° C
Laboratory 2	National Institute of Standards and Technology	ID Number	006	Baseline	5.942 m
Latitude	39° 59 min 44.494 s N	Counter Delay	-0.04 ns	Reference Source	UTC(NIST)
Longitude	105° 15 min 43.409 s W	REF Delay	748 ns	Mask Angle	10°
Altitude	1645.60 m	Receiver Delay	33 ns	Receiver Temp.	24° C

Hours in Common-View	Mean Time Offset (ns)	Range (ns)	Frequency Offset	Confidence (r)
237	-48.69	5.11	-1.19×10^{-16}	-0.04
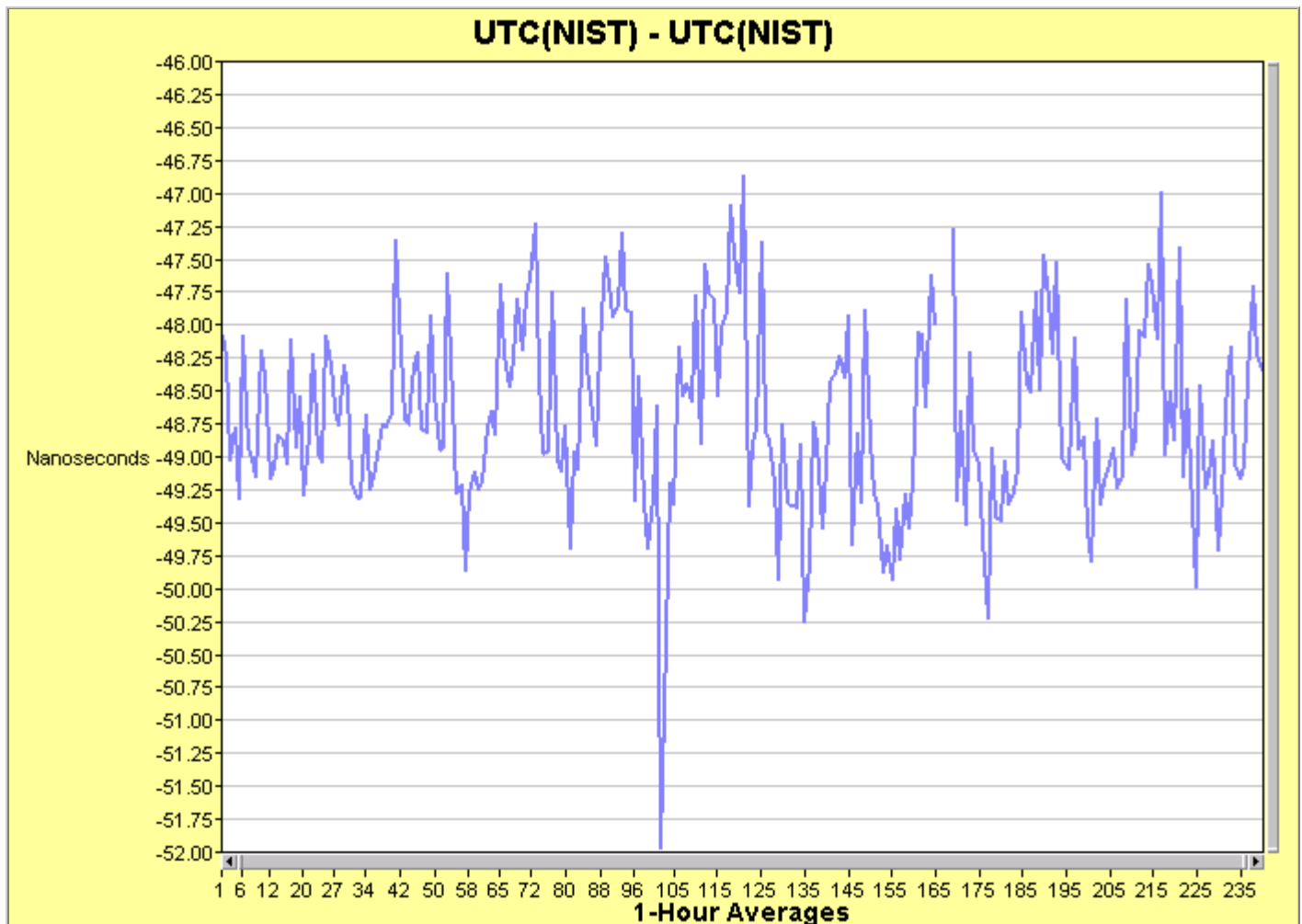
Allan Deviation

Averaging Time (τ) (hours, minutes)	Samples	Frequency Stability
0 h, 10 min	1415	2.73×10^{-12}
0 h, 20 min	1413	1.55×10^{-12}
0 h, 40 min	1409	7.52×10^{-13}
1 h, 20 min	1401	3.74×10^{-13}
2 h, 40 min	1385	2.05×10^{-13}
5 h, 20 min	1353	1.05×10^{-13}
10 h, 40 min	1289	5.42×10^{-14}
21 h, 20 min	1161	2.41×10^{-14}
42 h, 40 min	905	1.09×10^{-14}

Time Deviation

Averaging Time (τ) (hours, minutes)	Samples	Time Stability (ns)
0 h, 10 min	1415	0.94
0 h, 20 min	1412	0.79
0 h, 40 min	1406	0.59
1 h, 20 min	1394	0.45
2 h, 40 min	1370	0.36
5 h, 20 min	1322	0.37
10 h, 40 min	1226	0.53
21 h, 20 min	1034	0.21
42 h, 40 min	650	0.19

UTC(NIST) - UTC(NIST)
(common-view tracks from individual GPS satellites)

GPS PRN	Minutes (In-View)	Minutes (Common-View)	Range (ns)	Time Deviation	Frequency Offset	Confidence (r)	View Detail
1	3260	3260	17.26	2.01	-4.33×10^{-16}	-0.04	View
2	3630	3620	28.92	2.52	-6.49×10^{-16}	-0.04	View
3	4070	4060	21.05	2.30	-5.00×10^{-16}	-0.05	View
4	3040	3030	17.04	2.31	$+9.75 \times 10^{-16}$	+0.10	View
5	3720	3710	17.16	2.43	-3.88×10^{-17}	0.00	View
6	3340	3330	16.86	1.97	-4.15×10^{-16}	-0.05	View
7	3910	3910	15.85	2.03	$+2.40 \times 10^{-16}$	+0.02	View
8	3420	3420	15.37	2.04	$+1.50 \times 10^{-15}$	+0.13	View
9	3610	3600	18.34	1.77	-1.96×10^{-16}	-0.02	View
10	3750	3750	26.89	3.97	$+3.14 \times 10^{-16}$	+0.02	View
11	4210	4210	30.60	2.69	-4.42×10^{-17}	0.00	View
12	---	---	----------	-------	--------------	------	----
13	3130	3130	16.23	1.89	$+3.84 \times 10^{-16}$	+0.03	View
14	3760	3750	14.42	2.33	-1.06×10^{-15}	-0.11	View

GPS PRN	Minutes (In-View)	Minutes (Common-View)	Range	Time Deviation	Frequency Offset	Confidence Level (r)	View Track
15	3530	3530	18.73	2.24	-1.16×10^{-15}	-0.11	View
16	3860	3830	19.09	2.35	-3.61×10^{-16}	-0.03	View
17	---	---	----------	-------	--------------	------	----
18	3660	3660	13.72	1.75	-2.66×10^{-16}	-0.03	View
19	3480	3460	36.29	3.26	-1.30×10^{-16}	-0.01	View
20	3280	3280	32.34	3.53	$+9.42 \times 10^{-16}$	+0.06	View
21	3880	3880	16.70	1.98	-1.07×10^{-15}	-0.12	View
22	3610	3600	12.04	1.39	-1.78×10^{-16}	-0.02	View
23	3470	3470	16.67	1.93	-1.06×10^{-16}	-0.01	View
24	4110	4100	28.83	3.24	-2.39×10^{-16}	-0.01	View
25	3280	3280	20.45	2.41	-3.83×10^{-17}	0.00	View
26	3850	3850	21.26	1.95	-1.15×10^{-15}	-0.10	View
27	3750	3750	30.70	2.30	-7.93×10^{-16}	-0.07	View
28	3770	3770	14.12	2.16	$+1.17 \times 10^{-15}$	+0.11	View
29	4300	4300	16.27	2.19	-2.47×10^{-17}	0.00	View
30	3970	3970	18.87	2.54	-6.74×10^{-16}	-0.05	View
31	---	---	----------	-------	--------------	------	----
32	---	---	----------	-------	--------------	------	----

Legend	
GPS PRN	The unique pseudo random noise (PRN) code (1 to 32) used to identify each satellite. If no satellite is assigned to a given PRN code, then no data are shown.
Minutes (In-View)	The number of minutes when the satellite was visible at laboratory 1. During this period, the time difference between the satellite clock and the laboratory reference is measured every second, and 10 minute averages are stored. Since data is recorded in 10 minute segments, the values are even multiples of 10 minutes.
Minutes (Common-View)	The number of minutes when the satellite was visible at both to both receivers involved in the common-view comparison.
Range	The difference between the maximum and minimum time offset values (nanoseconds).
Time Deviation	The time deviation (TDEV) of the 10-minute averages (nanoseconds).
Frequency Offset	The estimated frequency offset of laboratory 1 relative to laboratory 2 based on a common-view observation of the satellite. This estimate is obtained by fitting a least squares line to all of the recorded data.
Confidence Level (r)	The confidence level of the estimated frequency offset. The confidence level is the correlation coefficient (r) of the least squares line fitted to the data.
View Track	Clicking on the View link displays a common-view track from the selected satellite. The number of previous days shown equals the number of previous days shown on this page, up to a maximum of 30 days.

Laboratory 1 / Identification Number	National Institute of Standards and Technology / 009
Reference Source	UTC(NIST)
Laboratory 2 / Identification Number	National Institute of Standards and Technology / 006
Reference Source	UTC(NIST)
End Date / Length of Calibration	2005-09-04 / 10 d

Main Plot and Statistics   Next Date   Last Date

Mean Time Offset (ns)	Range (ns)	Frequency Offset	Confidence (r)	ADEV at 1 day	TDEV at 1 day
-48.69	0.58	-1.91×10^{-16}	-0.31	1.78×10^{-15}	0.09 ns
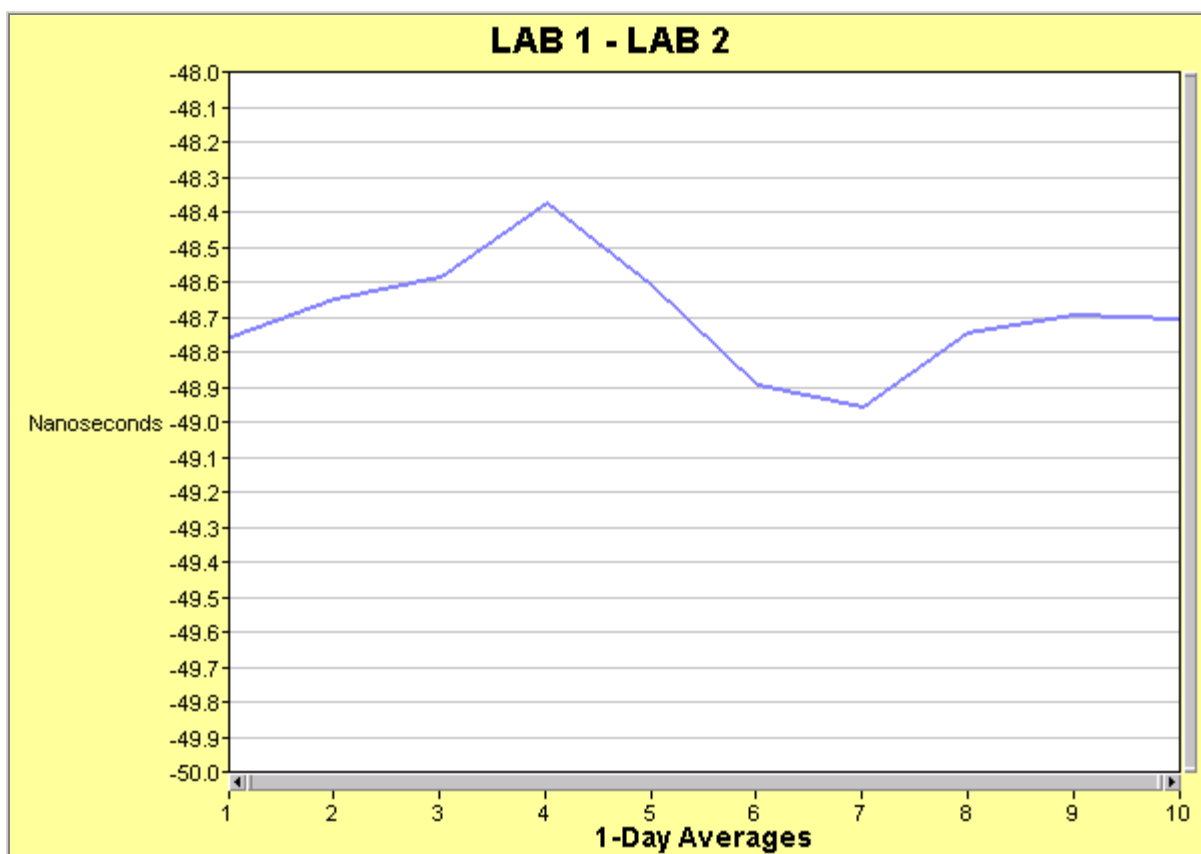
One Day Averages (LAB 1 - LAB 2)			
Point	Date	MJD	Value (ns)
1	2005-08-26	53608	-48.75
2	2005-08-27	53609	-48.64

3	2005-08-28	53610	-48.58
4	2005-08-29	53611	-48.37
5	2005-08-30	53612	-48.60
6	2005-08-31	53613	-48.89
7	2005-09-01	53614	-48.95
8	2005-09-02	53615	-48.74
9	2005-09-03	53616	-48.69
10	2005-09-04	53617	-48.70